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13. ABSTRACT *(Maximum 200 words)*

In this period the paper "Combined volume and surface scattering in a channel using a model formulation" by M.J. Beran and S. Frankenthal was presented at the May 1995 ASA meeting. The paper has been submitted for publication to the J. Acoust. Soc. Amer. A second paper entitled "Data analysis to determine vertical and horizontal correlation lengths of the random index-of-refraction fluctuations in a channel" by T. Barnard and M.J. Beran was also presented at the May ASA meeting. In preparation for calculations in channels with linear sound-speed profiles, programs have been written to calculate the necessary eigenvalues and eigenfunctions. We are also in the process of generalizing the equations governing the transverse scattering in channels. As a first step we have derived the spectral coherence equations for wide angle scattering in an unbounded medium to see the effect of the wide angle scattering. Finally, we considered the equations governing the two-frequency coherence function needed to calculate the propagation of time-dependent signals.

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The following topics were studied during the report period:

1) Combined volume and surface scattering in a channel, using a modal formulation.

2) Two-way formulation to account for backscattering in a channel. Spatial spectral analysis.

3) Data analysis to determine vertical and horizontal correlation lengths of the random index-of-refraction fluctuations in a channel.

4) The effect of random fluctuations on the two-frequency coherence function in a shallow channel.

5) Approximate eigenfunctions and eigenvalues for linear sound-speed profiles.

6) The effect of sea-water absorption on scattering in a shallow channel.

Topics 1-6 were reported upon in the previous progress reports (Jan. 1, 1994 - Oct. 31, 1994, Nov 1, 1994 - Dec. 31, 1994). The progress we have made since these reports is updated in this report. As we stated previously the work on topic 1 has been completed and a paper was submitted to JASA in December 1994. In addition, a paper has been presented at the May 1995 ASA meeting. A copy of the abstract is given below under topic 1. A paper has also been presented for the ASA meeting on the research performed in topic 3. This work was presented by T. Barnard, the doctoral student working on the contract.

1. Combined volume and surface scattering in a channel using a modal formulation.

A presentation on this subject was given at the May 1995 ASA meeting in Washington DC. The abstract of the paper is:

Combined volume and surface scattering in a channel using a modal formulation. Shimshon Frankenthal and M.J. Beran (Department of Electrical Engineering, The Catholic University of America, Cardinal Station, Washington, DC 20064)

In previous work, a modal approach was used to study random volume scattering in a shallow channel [M.J. Beran and S. Frankenthal, J. Acoust. Soc. Am., 91, 3203-3211 (1992)]. Here, the way to include the effects of a rough channel surface in the formulation is shown. To include the effects of a rough surface, the modes are taken to be dependent on the range and transverse coordinates in addition to the depth coordinate. The propagation is studied in terms of the ensemble-averaged two-point coherence function and the equation governing the coherence function is derived. In order to insure energy conservation when the generalized modal field equations are simplified, the parabolic approximation is replaced by a method which includes both forward and backward propagating fields. The two-point coherence function is expressed as the sum over both self-modal and cross-modal coherence functions. The difference between the equations governing the self-modal coherence functions and the cross-modal coherence functions is considered. A numerical example which uses typical shallow water parameters is presented. Figures portray

how the mode energies are transferred between the modes as the acoustical field propagates. (This work was partially supported by ONR).

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2. Two-way formulation to account for backscattering in a channel. Spatial spectral analysis.

In order to clarify the conditions for validity of the differential and integro- differential equations that we have derived for channels we have considered the deep ocean case where the boundaries play no role. Using a transverse wavenumber approach we were able to generalize equations previously derived for wide angle propagation through anisotropic random media like the deep ocean.

We have also used a combination of a modal analysis in the channel depth direction and a spectral analysis in the transverse direction. Thus, instead of a partial differential equation with transverse derivatives we obtain an integro -differential equation. We are presently using the transverse spectral approach in order to consider wide angle scattering in the transverse direction. In our previous work we have restricted our analysis to small angle scattering in the transverse channel direction.

3. Data analysis to determine vertical and horizontal correlation lengths of the random index-of-refraction fluctuations in a channel.

A paper based on the following abstract was presented at the May 1995 ASA meeting in Washington DC:

Determination of vertical correlation lengths in a channel using SWELLEX-1 thermistor data. T.Barnard and M.J. Beran (Department of Electrical Engineering, The Catholic University of America, Cardinal Station, Washington, DC 20064)

In order to properly determine the volume scattering in a channel, it is necessary to know the characteristic vertical and horizontal correlation lengths associated with the random index-of-refraction fluctuations. The results we have obtained for characteristic vertical correlation lengths using SWELLEX-1 vertical-array thermistor data are discussed. The data has been analyzed for day-time and night-time observations. In addition, the results are dependent upon averaging times and this effect is discussed. Graphs are given for the standard deviation and normalized cross-correlations of the fluctuations, as a function of depth. (The vertical temperature data analyzed in this presentation was produced by NRL Code 7120 and NRAD Code 541 under ONR sponsorship. The data was supplied to us by B. Pasewark of NRL Code 7120. Our analysis was supported by ONR).

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4. The effect of random fluctuations on the two-frequency coherence function in a shallow channel.

Rather than complete the numerical calculations for a restricted class of frequency differences we have devoted our attention to obtaining a formulation that is valid for all frequency differences. We find there is a group of frequency differences for which we are unable to reduce the difference equation we obtain to a differential equation. By varying the range increment we use in the difference equation we were able to treat a larger class of frequency differences by a differential equation but we still have not succeeded in replacing the difference equation by a differential equation for all frequency differences.

5. Approximate eigenfunctions and eigenvalues for linear sound-speed profiles.

In the paper in Sec. 1, numerical calculations were included for a constant sound-speed profile. The same calculations will be done for a linear sound-speed profile. Mr. Barnard, the Ph.D. student, has written up his analysis for determining the eigenfunctions and eigenvalues for the linear profile and generalized his approach to include piecewise linear profiles. He has also been considering bottom boundary conditions that are represented by an impedance condition. In the near future he will begin calculating the scattering coeffients for the linear profile.

Mr. Barnard presented his Ph.D. research proposal to the Electrical Engineering faculty at The Catholic University of America on Feb. 16, 1995 and it was approved.

6. The effect of sea-water absorption on scattering in a shallow channel.

We are still completing the numerical calculations to determine the effect of sea-water absorption. As we stated previously all the theoretical calculations have been completed. A draft abstract was given in the last progress report. The reason that the calculations have not yet been completed is that at the higher frequencies where absorption is important (5-10 kHz), there are more propagating modes. Previously, we easily numerically solved a coupled set of 60 ordinary equations. Now, however, we would like to solve a coupled set of about 500 equations and are looking for a way to more effectively use off-hour computing facilities. We can reduce the mode numbers by using shallower channels but we prefer to have a computing procedure that does not have this limitation.